THEORETICAL ASPECTS OF HIGH ENERGY PHYSICS

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The study of cosmic rays and especially the research made recently with accelerators have led to the discovery of a whole world of elementary particles.

At present it has become clear that elementary particles themselves are complicated objects, which are likely no less complex than atoms and molecules. This is proved by the existence of a system of baryons which may be treated as sequence of excited nucleon states. The existence of resonances in the baryon-meson system is also proved. The concept of the nucleon form-factor and the polarizability of the nucleon has appeared as well.

Another important feature is the recent discovery of resonant states in the system of interacting mesons, which suggests a complex structure for mesonic matter. Different decay modes of baryons and nucleons also emphasize the great richness and variety of the microphenomena. As we go further into this world, the requirements on accelerators and experimental apparatus are becoming higher. One may feel an apparent trend to construct accelerators of the highest energies and intensities possible. It is a salient feature of the up-to-date experiments to obtain pure beams of different particles, to build up big chambers and hodoscopic systems for detecting events, as well as automatic machines and electronic computers meant for analyzing the information.

There are all grounds to believe that these trends will remain true in the future and will require ever greater expenditures and efforts of many people.

So, it seems to be very important to analyze what kind of theoretical information may facilitate progress most effectively.

This report is an attempt at such an analysis.

I. Theory

Modern conceptions based on quantum field theory prove to be effective when they describe the properties of free stable particles and unstable ones if the radioactive decay occurs slowly enough. It appears possible to characterize particles by concepts, well-known in quantum field theory (particle mass, charge, spin, isotopic spin, parity, strangeness). The adequacy of this description confirms the effectiveness and correctness of the modern theory as far as free particles are concerned.

Quite an opposite situation is met when we try to calculate particle interactions. It seems that in a most general form such calculations may be made in two cases:

a) when one can make use of perturbation theory, as is the case in the theory of electromagnetic or weak interactions;

b) when one succeeds in sticking to the most general principles of the modern theory as, for instance, in the theory of dispersion relations and in "Reggistics".

Both these methods are limited in their applications and are very far from being able to predict theoretically the properties of the existing particles and the results of their interactions.

It is essential that the basic principles of the modern theory still rest on quantum field theory which is a certain synthesis of quantum theory and relativity.

This synthesis, which is, of course, far from being ideal, was accomplished in the thirties. Since then the following modifications have been made:

a) Relativistic invariant perturbation theory and relativistic invariant renormalization theory (removal of infinities) have been developed.

b) The fundamental significance of causality has been understood, which led to the appearance of dispersion relations as well as "Reggistics" (analytical properties of the scattering matrix).

However, one has to conceive clearly that no essential changes seem to have taken place in the basic principles of the theory.

In spite of a good deal of experimental results accumulated in the domain of high energy physics, none of the experiments so far have led to a contradiction of the main principles of modern theory, i.e. of the general principles of relativity and quantum mechanics. At present there is no phenomenon which would contradict the modern theory where it is capable of predicting a reliable number. One may expect that this consistency of theory with experiment may be violated for smaller collision parameters.

II. "Elementary" length

At the present time experiment covers the range of baryon wavelengths 10^{-14} cm. The advance to the region of even smaller scales was followed, as usual, by the appearance of principally new physical phenomena having their own specific properties. This allows one to believe, that in the small space-time intervals the main conventional laws are to be violated. This widely discussed idea may come true.

We shall speak about a certain elementary length which characterizes the space-time interval where the supposed essential violation of the conventional laws occurs.

The purpose of physics of the near future is to investigate thoroughly the phenomena described by the physics of small lengths. These tasks can be accomplished either with accelerators in which extremely high energies of the accelerated particles are attainable, or with machines of lower energies but very high intensities of particle beams. It would in principle be possible, by making relatively rough measurements, with the ultra-high energy accelerators to record the inconsistency with the theory should it become greater with increasing energy. Accelerators with very intense particle beams could have led to the same result if precise measurements are made already in the energy ranges where these divergences are small.

Our forecasts will essentially depend on what length is to be chosen for the role of the fundamental length of the microworld. It seems there are three such pretenders: $a_0 \approx 10^{-13}$cm (the electromagnetic radius of the electron $e^2/mc^2 = 2.8.10^{-13}$cm or the Compton wave length of the pion $\hbar/\mu c = 1.4.10^{-13}$cm), $a_M = \hbar/Mc = 2.10^{-14}$cm (the Compton wave length of the nucleon), $a_F = \sqrt{\frac{G}{\hbar c}} = 6.10^{-17}$cm (a characteristic wave length of weak interactions).

The first of these seems to be too large. One can hardly expect that with the present experimental facilities this length would be considered critical. There are other universal "lengths" shorter than 10^{-16}cm but they are still far beyond the up-to-date experimental possibilities. So, we will not discuss them now. The most probable candidates for the role of an elementary length remain now a_M and a_F. This imposes certain requirements on future accelerators. Let us consider the case when the expected length will be of order of 10^{-14}cm.

Here a study of strong interactions will prove to be most important. At the same time one should have the meson and nucleon momentum in the centre-of-mass system to be $p > Mc$. Such a magnitude of momentum is now attainable with up-to-date accelerators (at Dubna $p \approx 2Mc$, at CERN, Brookhaven $p = 3.7Mc$, at Serpukhov p will amount to about 6 Mc).

Therefore, if the critical elementary length is a_M then the modern accelerators may yield very important new information.

The estimates show that for $\pi^{\pm}p$ - scattering at 180° accompanied by a great momentum transfer the accelerators presently available can be utilized. For $K^{\pm}p$ -scattering it will be necessary to increase essentially the intensity of $K^{\pm}$ beams ($\approx 10^2$ times).

When the elementary length turns out to be $a_F \approx 10^{-16}$cm the situation will be extremely unfavourable, since for studying so small scales a particle energy of more than 100 GeV in the c.m.s. will be needed.

What departures from the general laws may be expected? First of all, we think that no change in the laws of energy and momentum conservation should take place[x]. These laws are connected with the translational invariance in space-time of the whole interacting system, and it seems that there are no reasons for its violation. None the less, one may think of some theoretical schemes in which the translational invariance is not fulfilled. So, as far as this problem is concerned, we ought to be attentive to the experimental results.

Still it appears more likely that we have to be ready to face any surprises whatsoever concerning relative particle motion (i.e. just the motion in which particle interaction is displayed).

Let us now turn to elastic particle scattering. It is determined by the scattering amplitude A which depends on the two invariants $t = q^2$ (q is the momentum transfer) and $s = w^2$ (w is the total energy):

$$A = A(s, t)$$

That A depends on s and t can be altered by no "tricks" whatsoever at small distances. Nor the relativistic invariance (covariance) of the amplitude can be violated, since this property is determined by large asymptotic distance for which there are no grounds to doubt the applicability of the Lorentz transformation. Therefore, if the scattering amplitude $A(s,t)$ depends on the elementary length a as well: $A = A(s,t:a)$, then this dependence can lead neither to a violation of conservation laws, nor to a violation of the Lorentz invariance.

However, the departure from the conventional geometry laws or causality at small distances may lead to a change in the analytical properties of the scattering amplitude and, therefore, dispersion relations. When causality is violated dispersion relations will not be fulfilled at all, or will be modified.

In particular, in case of a sharply limited space-time region, inside which causality is violated, dispersion relations will hold true for the quantity

$$\tilde{A}(s,t:a) = A(s,t:a)\, e^{i\psi} \quad \text{where} \quad \psi = a\phi(s,t) \text{ rather}$$

than for the scattering amplitude $A(s,t:a)$. The quantity ψ may serve as a

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x) Such a possibility would be rather met in the general theory of relativity in the macroworld than in the microworld.

measure as to how far we depart from the usual dispersion relations. For the forward scattering $\psi = aE_0$, where E_0 is the meson energy in lab. sy... Hence $a = a_M = 2.10^{-14}$ cm, then one should expect most serious violations of dispersion relations for mesons of energy of 1 GeV.

For $a = a_F = 10^{-16}$ cm the situation will be much more unfavourable; in this case at $E_0 = 10$ GeV, $\psi = 0.04$; at $E_0 = 30$ GeV, $\psi \approx 0.10$ and at $E_0 = 70$ GeV, $\psi = 0.20$. Irrespective of the character of a possible violation of dispersion relations, their verification presents, especially for πN scattering, a fundamental problem in studying strong interactions (in the case of NN scattering dispersion relations have a large non-physical region. For this reason, nucleons turned out to be not so fortunate objects for studying this problem).

As far as practical realization of this verification is concerned, it should be noted that with accelerators presently available it is possible to measure ReA with an accuracy of 5÷10% in the energy region up to 10 GeV for πN -scattering and up to 30 GeV for NN scattering in the forthcoming years.

An accuracy of about 1% would require an increase in the beam intensity not less than by two orders. To measure the total cross section σ_{tot} which enters into dispersion relations it is necessary to make use of accelerators with extremely high energies of 50 ÷ 100 GeV. At this energy, according to the available data, one may expect that the total cross section σ_{tot} reaches its asymptotic value for most of the particles. The requirements to the intensity of the accelerator for making this measurement are the usual ones - of the order of 10 particles per pulse.

Another important example of experiments in which emphasis is on a variety of beams and high detection efficiency of events, rather than on particle energies is given by experiments on a check of CPT - invariance. A verification of the CPT-theorem is very essential for the theory, since its proof rests on a postulate of locality (in its modern general formulation(and does not contain, besides the main axioms, any particular hypothesis (like hypothesis of the Lagrangian method etc). The CPT - theorem can be verified in experiments on measurement of the perpendicular polarization components e^+ and e^- in the cascades $\pi^\pm \to \mu^\pm \to e^\pm$, $K \to \mu \to e$ in the decays $K_{\mu 3}$ and $K_{e 3}$ in the experiments on the measurements of the perpendicular components of nucleon and antinucleon polarizations in the cascades

$$\tilde{p} + p \to Y + \tilde{Y}, \quad Y \to N + \pi, \quad \tilde{Y} \to \tilde{N} + \tilde{\pi}$$

To perform these experiments the most essential thing is to make progress in the detection technique of the antinucleon appearing in the decay $\tilde{Y} \to \tilde{N} + \pi$

It seems that a complicated combination of electronics, spark and emulsion chambers will be required.

One may assert that the effective instrumentation will allow to determine the longitudinal components of nucleon polarization already with the presently available accelerators.

III. Electromagnetic interactions

Essential progress in revealing possible contradictions of field theory with experiment can be achieved by studying the electrodynamical effects. First and foremost, this is due to the fact that for particles which do not suffer strong interactions we have a consistent theory of electromagnetic interactions (quantum electrodynamics) which is well checked experimentally with electrons.

However, at great momentum transfers, even for these particles (for instance, in elastic electron scattering) we are confronted with a little studied violation of electrodynamics which is due to a pure electromagnetic production of meson and nucleon pairs.

So far charged vector mesons (ρ, k^*) have been discovered. The intermediate vector bosons responsible for weak interactions are supposed to exist.

However, there is yet no consistent theory of the electromagnetic interaction of vector particles.

It is likely that already in this case the electromagnetic interaction is mixed up with the strong one.

Just at the point where strong interactions become essential theory is faced with difficulties of principle.

In particular, the electromagnetic interaction of strongly interacting particles, for instance, nucleons may be calculated in the region of low electromagnetic frequences when particles may be characterized by charges, magnetic moments and polarizabilities (both magnetic and electric).

The study of the link between the electromagnetic and strong interactions may become a subject of a wide range research. Among them, we may point to:

1. The study of the applicability of the basic principles of modern theory to electromagnetic interactions of strongly interacting particles. So, for instance, one may conclude from the basic principles of the theory that the form-factors at $t=-q^2\to\pm\infty$ for the process $e^{\pm}+p\to e^{\pm}+p$ and $\tilde{p}+p\to e^{+}+e^{-}$ must be identical. The verification of this conclusion would be a check on the locality of the theory.

2. The study of the production of strongly interacting particles in the anni-

hilation of electromagnetic interacting particles, for instance, the processes in colliding beams

$$e^{+} + e^{-} \rightarrow \left\{ \begin{array}{l} \pi\pi \\ N\tilde{N} \\ etc \end{array} \right.$$

and the inverse ones, for example, $N + \tilde{N} \rightarrow e^{+} + e^{-}$

For studying the former processes we shall be in need of accelerators with colliding beams (or storage rings) with the beam particle energy from 200 MeV up to 1.5 GeV and higher and with the beam current of more than 10 Ma. A study of the inverse process is already possible on modern accelerators in pure antiproton beams.

3. A study of electron scattering by nucleons (eN) and pions by electrons (πe) will yield the most valuable information on the charge and current distribution in strongly interacting particles. In these experiments it is desirable to study processes with a momentum transfer more than 1 GeV/ c.

4. Scattering of pions by electrons will allow a study of the electromagnetic structure of the pion.

To perform there experiments it will be necessary to construct accelerators with an energy of above 100 GeV and with intensity of 10^{12} particles per pulse!

5. Photoproduction of resonons on nucleons and production of vector particles in the Coulomb field. This kind of research may be performed with modern electron accelerators with an energy of 1 GeV.

6. The Compton effect and photoproduction of mesons on nucleons have not been sufficiently studied either. Here it is of interest to study precisely both threshold region and high energy processes with momentum transfers of more than 1 GeV.

7. A special place is occupied by μ -meson. It would be extremely important to find the distinction of its electromagnetic properties from those of an electron. According to the gyromagnetic ratio measurements one may believe that this distinction will be beyond 10^{-14} cm, i.e. for the momentum transfers greater than 1 GeV/ c.

As is seen from this brief sketch, theory is capable of outlining a great variety of investigations on the connection between the electromagnetic and strong interactions where the discovery of non-trivial and unexpected events seems to be very probable.

The connection between the electromagnetic and weak interactions will be discussed in the last chapter of this report.

IV. Strong i eractions

At high energies there may occur a much greater variety of processes and effects than at low energies. We outline the main ones:

1. Ever larger number of particles is produced per collision. It is of great *interest to analyze thoroughly the character of multiple pion production in view of* the existence of high excited states which decay into pions. In the light of recent discoveries made with accelerators of new resonant states, on the one hand, and of the existence of the effect due to the so-called "fireballs" in high energy cosmic rays, on the other, one is naturally led to think that there is a infinite number of similar short-lived states of matter, decaying into π -mesons.

2. At high energies antinuclei with ever larger atomic number will be created.

3. The appearance of new particles and resonances is possible. Of principle importance for the theory will be to investigate whether at high energies the conservation laws are fulfilled or not (conservation of isospin, strangeness, parity conservation, conservation of G -parity, and of charge conjugation). It is also important to study some possible approximate symmetries of strong interaction (eightfold way, unitarity symmetry, γ_5 - invariance etc).

The recent development of theoretical concepts based on general ideas of analyticity and unitarity has led to a number of essential conclusions which should be experimentally verified in the high energy region. Especially great progress was made recently in the theoretical investigation of the asymptotic behaviour of strong interactions when physicists succeeded in connecting the general principles of analyticity and unitarity with the complex angular momentum technique.

It turns out that when the energy is especially high there arise essentially simpler physical situations which allow one to extract the directly observable consequences from the general theoretical concepts.

We would first like to draw attention to the conclusions following from the most general principles of local field theory. They mainly concern the asymptotic relations between cross sections at high energies. We stress the following relations which may be checked experimentally:

1. Equality of the total interaction cross sections for particles and antiparticles at high energies

$$\sigma_{tot}(pp) = \sigma_{tot}(\widetilde{pp})$$

$$\sigma_{tot}(\Sigma N) = \sigma_{tot}(\widetilde{\Sigma} N)$$

$$\sigma_{tot}(\pi^+ p) = \sigma_{tot}(\pi^- p) = \sigma_{tot}(\pi^0 p)$$

2. The asymptotic equality of the differential cross sections at the fixed momentum transfers

$$\frac{d\sigma}{dt}(\pi^+ p \to \pi^+ + p) = \frac{d\sigma}{dt}(\pi^- p \to \pi^- p)$$

$$\frac{d\sigma}{dt}(\pi^+ p \to K^+ \Sigma^+) = \frac{d\sigma}{dt}(K^- p - \pi^- \Sigma^+)$$

$$\frac{d\sigma}{dt}(Np \to Np) = \frac{d\sigma}{dt}(\tilde{N} p \to \tilde{N} p)$$

3. A relationship between the total cross sections and the forward differential cross section

$$\frac{d\sigma}{dt}(\pi^+ p \to \pi^+ p)/_{t=0} - ½ \frac{d\sigma}{dt}(\pi^- p \to \pi^0 n)/_{t=0} =$$

$$= \frac{1}{16\pi} \sigma_{tot}^2 (\pi^+ p)$$

4. The asymptotic equality of the form-factors at $t = -q^2 \to \pm\infty$ makes it possible to connect the cross sections for the processes $e + p \to e + p$ and $p + \tilde{p} \to e + \tilde{e}$ (see chapter III).

5. Dispersion relations may also be referred to the consequences following from the most general principles of the theory.

They were discussed in Chapter II. The requirements to the accelerators imposed by the experiments on the check of the above asymptotic relations are about the same as those considered earlier in connection with a verification of dispersion relations.

Now we point to some interesting and important consequences of the theory which, however, result from more particular additional assumptions. Indeed, if we suppose that the Mandelstam representation for the scattering amplitude is correct and that the asymptotic behaviour of the amplitude is determined by the poles in the angular momentum plane (Regge poles), we can draw some important conclusions:

1. Elementary Particles and Bound States. One of the most important problems in physics is whether there is any principal distinction between objects, which we call elementary particles, and compound systems like atoms and molecules. The poles in the elastic scattering amplitude correspond both to elementary particles and to bound states. In the case of compound particles these poles are the moving ones in the plane of complex momenta (i.e. their orbital momentum j depends on the energy $\sqrt{t}$). If the poles corresponding to elementary particles had displayed the same behaviour, it would have been a strong argument in

favour of the absence of a principal difference between compound and elementary particles.

A study of elastic scattering of positive pions on protons at the given magnitude $u=(p_1-k_2)^2$ (p_1 is the initial 4-momentum of the proton, k_2 is the final 4-momentum of the pion) throws some light on this problem. At the same time $|u|$ should be small compared with s , i.e. the scattering angles are close to 180°. If $(\frac{d\sigma}{d\Omega})_{u=const}$ tends to zero, when $s \to \infty$ then the proton pole is a moving one. Similar experiments on K-meson scattering by protons yield the same information on Λ , Σ hyperons. This set of experiments may be extended in order to include ρ and K mesonic poles.

In order to perform this experiment on π^+ -scattering at 180°, at an energy of some GeV, the accelerators of the modern type are sufficient. If this experiment is done at an energy of about 50 GeV then in the case of the fixed proton pole, an intensity of about 10^{11} particles per pulse will be required.

When the pole is a moving one, it is necessary to have 10^{15} particles per pulse.

K-meson will require an intensity by two-three orders more compared with the estimates for π mesons.

2. States of Different Symmetry and Isotopic Spin at High Energies. When different isotopic states (for instance, elastic π^- scattering on protons) contribute to the reaction, yet at $s \to \infty$, there must exist quite definite isotopic relations of a special type. It is characteristic of them, that in the transition from the t channel) (t is the four-dimensional momentum transfer squared) to s at $s \to \infty$ only one definite value of the isotopic spin is essential. This conclusion is correct if the degeneracy in the isotopic spin is assumed to be absent in the crossed channel. Such inverse isotopic relations may be exemplified by the ratio of the differential reaction cross sections at $|u| \ll s$, i.e. at the angles close to 180°:

$$1)\quad \pi^+ + p \to \pi^+ + p \qquad 2)\ \pi^- + p \to \pi^- + p \qquad 3)\ \pi^- + p \to \pi^0 + n$$

The ratio (1); (2); (3) may be equal to 1:9:2 or to 2:0:1. The number of such examples may be increased. Peculiar relations hold between the elastic scattering cross sections and the annihilation ones. When the degeneracy of the symmetrical and antisymmetrical states is absent, the differential elastic scattering and annihilation cross sections at the given values of t or u and with $s \to \infty$ must coincide. One of the examples is $\pi^+ + p \to \pi^+ + p$ in the angle interval close to 180°. The other $p + \tilde{p} \to \pi^+ + \pi^-$ takes place when the positive pion in the annihilation channel travels in a direction close to that of the proton (both the cross sections for their reactions are compared at u = const and $s \to \infty$).

3. Universality of Asymptotic Behaviour of the Cross Sections for Different Systems. This problem may be exemplified by elastic scattering of $\pi^{\pm}$ mesons $K^{\pm}$ mesons, protons and antiprotons on protons. When the momentum transfer $\sqrt{t} = 0$ this problem is connected with that of universality or non-universality of the asymptotic behaviour of the total cross sections. It follows from the unitarity relations that in all the systems which have been in the t -channel all familiar quantum numbers equal to each other (the example we have chosen belongs to that class) the total cross sections necessarily display a peculiar universal behaviour. All the total cross sections should satisfy the equality:

$$s^{\epsilon} > \sigma_{tot} > s^{-\epsilon} \ , \quad \epsilon > 0 , \quad \epsilon \to 0$$

if, at least, in one of the systems σ = const. Thus, the asymptotic behaviour of all the total cross sections may differ in only the functions dependent on energy weakly (logarithmically). When the momentum transfer $\sqrt{t} \neq 0$ there is reason to believe that this important conclusion will hold true. In the channels with other quantum numbers the situation is the same: for instance, the behaviour of the cross sections for $\pi^- + p \to \pi^0 + n$ and $K^- + p \to K^0 + n$ must be (up to logarithmic functions) identical. In to-day experiments on elastic scattering of $\pi^{\pm}$, $K^{\pm}$, p and $\tilde{p}$ on protons for each reaction its own behaviour of the differential cross sections was found. The study of the behaviour of these cross sections will be continued on accelerators with limiting energies and moderate intensities 10^{11} particles per pulse! If at high energies the latter phenomenon occurs, this result will be of great significance and may entail important physical consequences.

4. Oscillations in the Elastic Scattering of π and K Mesons by Nucleons at Angles Close to 180° at High Energies. The theoretical treatment of this problem has shown that when there is no degeneracy in the partial waves with the same total angular momentum and different parities in the differential cross sections of the above processes just as in different polarization experiments, there must be peculiar oscillations in the behaviour of the cross sections. A study of these oscillations imposes the same requirements to the beams as that of the backward scattering.

5. Problem of the Constant Cross Section and Shapes of the Elastic Scattering Peaks. It was believed for a long time that the obvious shape of the elastic scattering amplitude in the diffraction region $|t| \ll s$ in the form $sf(t)$ (the absorption and refraction coefficient independent of energy and determined

by the impact parameter only) cannot be consistent with unitarity and analyticity in a simple manner. It requires an existence of moving branch points in the complex angular momentum plane which have been so far little studied. It should be added that the proportionality of the amplitude to the first power is a limiting special case since in the physical region a power higher than the first one is inconsistent with dispersion relations. This limiting situation is likely to suggest a more complicated physical and mathematical picture of diffractional scattering compared with that described by a leading single vacuum Regge pole. A thorough experimental investigation of all these problems is thought to be very important. These problems are as follows:

a) A study of the differential elastic scattering cross sections of $\pi^{\pm}$, $K^{\pm}$, $\tilde{p}p$, $\tilde{n}n$ and $\tilde{\Lambda}\Lambda$, $\tilde{\Sigma}\Sigma$ and $\tilde{\Xi}\Xi$ on protons at $|t| \ll s$; b) A study of the behaviour of the real parts of the scattering amplitude (for instance, by interference with Coulomb scattering); c) A measurement of different spin effects in such elastic scattering. The special place occupied by the elastic diffraction scattering among other processes (any inelastic process contributes necessarily to the diffraction scattering) attaches great importance to experiments to be performed in this energy range.

6. <u>Vanishing of the Charge Exchange Cross Sections and Polarizations at High Energies.</u> It follows from general considerations that if there is no degeneracy in isotopic spin in the t-channel, the charge exchange processes of the type:

$$\pi^- + p \to \pi^0 + n\ , \quad K^- + p \to K^0 + n\ ,\ n + p \to n + p$$

(charge exchange scattering of neutrons by protons) should have cross sections which tend to zero. From the same reasons one is led to a conclusion that the polarization in elastic scattering processes disappears asymptotically. Hence one may conclude that pp and np, $\Sigma^+ p$ and $\Sigma^- p$ etc. are asymptotically equal. This also holds for other similar processes. The total cross sections for the reactions

$$K^- + p \to \Lambda + \pi^0\ , \quad \pi^- + p \to \Lambda + K\ , \quad K^- + n \to \Lambda + \pi^-$$

etc should tend to zero. Note that the measurement of the charge exchange reactions (for instance, $\pi^- p$) in the range of some GeV requires an increase in the intensity of the extracted beams by the two orders.

7. <u>The Asymptotic Behaviour as Described by the Hypothesis of Moving Regge Poles.</u> If the singularity having the largest value of the real part in the

complex angular momentum plane of the corresponding crossed channel is an isolated Regge pole, a very simple picture of the asymptotic behaviour takes place:

a) $\frac{d\sigma}{dt}$ (or $\frac{d\sigma}{du}$) of all the processes with identical quantum numbers in the crossed channel are determined by

$$\frac{d\sigma_{ik}}{dt} = |\gamma_i|^2 |\gamma_k|^2 s^{2(\alpha(t)-1)}$$

b) the following relationships between the differential cross sections hold

$$\frac{d\sigma_{ii}}{dt} \quad \frac{d\sigma_{kk}}{dt} = \left(\frac{d\sigma_{ik}}{dt} \right)^2$$

c) all these processes have the same spin structure

d) all these processes have the same ratio of the real and imaginary parts.

Example: both the reactions $\pi^- + p \to \pi^0 + n$ and $n + p \to n + p$ go with the same power of energy;

e) the presence of oscillations in backward scattering of π and K mesons;

f) simple relations describing the manner as to how the cross sections tend to their asymptotic value;

g) the connection between the powers of energy governing the difference σ_{tot} of $\pi^- + p$ and $\pi^+ + p$ with that entering the charge exchange. Other examples of similar nature can be found;

j) an increase of the radius of nuclear forces with energy. One may think, therefore, that at high energies the nuclear cross sections must not be proportional to $A^{2/3}$. It should be noted that the presence of moving branch points in the plane of complex angular momentum may complicate the picture of elastic diffraction scattering (as has been pointed out above). However, in other channels (a change of the charge, of spin, backward scattering, strange particles) there are grounds to think that this will not happen.

8. <u>The Radius of Nuclear Forces and Nuclear Cross Sections.</u> There are some reasons to suppose the existence of moving singularities in the ℓ -plane of the crossed channel of the two-particle reactions. Irrespective of whether they are leading ones or not, the very fact of their existence entails the appearance at high energies of a strong interaction component with a radius growing logarithmically with energy. This effect becomes even more important if the leading singularity is a moving one (irrespective of the character of that singularity). If in the diffraction region of elastic scattering the asymptoic behaviour is determined by a single vacuum Regge pole or if we have $s f(t)$ (standing pole) some relations between the total cross sections take place which are inconsistent with the propor-

tionality of the nuclear cross sections $A^{2/3}$. In this case one may see that the total nuclear cross sections must be proportional to A at very high energies. Precise experiments performed in this energy region are very important. High accuracy is essential because the energy range of the transition from $A^{2/3}$ to A may turn out to be wide.

9. Connection of the Mass Spectrum of Particles and Resonances with Asymptotic Behaviour of Strong Interactions. The Regge poles govern the asymptotic behaviour of strong interactions at $t < 0$ while for $t > 0$ they give rise to particles or resonances when passing through integral numbers of the correct signature.

A thorough experimental investigation of the dependence $a(t)$, $a(u)$ in all the channels, where we are faced with a purely pole type asymptotic behaviour, will surely yield valuable physical information which allows a resonable classification and systematization of particles and resonances. On the other hand, the particles and resonances presently available permit one to derive theoretical formulae which describe the manner how the cross sections tend to their constant values for the energy dependence of the differential and total charge exchange cross sections, for the energy dependence of the differential and total cross sections for strange particle production etc. An experimental investigation of the trajectories of Regge poles in the channels where they will be actually found is, undoubtedly, one of the most important tasks which experiment faces to-day.

10. The Asymptotic Behaviour of Inelastic Processes Involving Production of Many Particles. Among the variety of fundamental problems encountered in this field which is still little studied because of theoretical difficulties, it is necessary to single out questions pertaining to the asymptotic behaviour of the processes of small multiplicity of the type $2 \to 3$, $2 \to 4$. It seems that these processes must have a cross section falling slowly with increasing energy s. It is also interesting to clear up the energetic behaviour of the processes in which unstable particles of the type $\pi^- + p \to n + \pi^0$, $\pi + p \to n + \omega$, $\pi + p \to N^* + \pi$ etc are produced. There are grounds to believe that these processes fall into the general scheme of Regge poles. In this case quite a definite energy dependence is obtained for these reactions. For instance, the cross section for the reaction $\pi + p \to N^* + \omega$ may have the same power as the charge exchange cross section of $\pi^- + p \to \pi^0 + n$.

IV. Weak Interactions

The modern theory of particles has at its disposal two essentially different mechanisms for describing weak interactions:

a) The electrodynamical analogue: point interactions involving intermediate real or virtual fields of different "boson" dimensionality (vector, pseudovector etc).

b) The four-fermion interaction itself without the intermediate boson field. That is how weak interactions are described.

Such a duality is so strongly opposed (may be as a result of an instinctive striving for monism) that two tendencies have appeared which have, in fact, to be taken into consideration:

a) To reduce all the interactions to those of the electrodynamic type. This means that for weak interactions the so-called intermediate boson is supposed to exist.

b) To reduce the interactions of the electrodynamic type to the four-fermion interactions (bosons as compound particles etc).

And, finally, the third possibility consists in preserving duality which is discussed here.

In this situation it is of primary practical importance for the research performed on high energy accelerators to look for intermediate mesons in all the energy ranges starting from $m_w \approx m_k$, m_k being the K-meson mass. Unfortunately, there are yet no essential theoretical considerations concerning the magnitude of a probable mass for the intermediate meson. One can merely assert that the search for the intermediate meson is meaningful and is likely to be undertaken within the mass region

$$m_K < m_W < \sqrt{\frac{\hbar c}{G}} = 300 \text{ GeV}$$

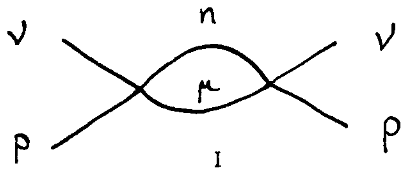
If physics is very "lucky", i.e. the mass of the intermediate meson turns out to be close to the lower boundary of the inequality, then the problem concerning the intermediate meson with all the resulting consequences may be solved with Brookhaven and CERN accelerators. If this mass turns out to be much larger and closer to the upper limit of the inequality, then this problem is likely to remain one of the fundamental problems in high energy physics for some decades.

It may appear that in the search of the intermediate meson in the mass region beyond that of the masses a neutrino beam will fail to be more effective than, for instance, colliding electron-positron or photon beams. Thus, the problem of the intermediate meson may become that with which high energy accelerators of all the types are confronted.

In the theory of weak interactions one may conceive widely discussed interactions of the type $(e\nu)(e\nu)$ or $(p\nu)(p\nu)$, $(pn)(pn)$, $(pn)(p\Lambda^0)$ etc which could be essential in nature, since the existence or absence of such interact -

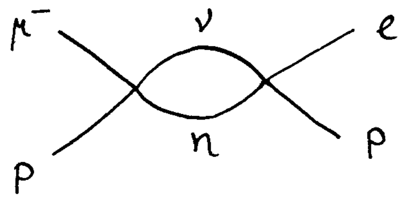
ions may substantially modify the basic principles of the theory of weak interactions. At present it has become practically possible to detect, with the accelerators like in Brookhaven or at CERN, $(p\nu)(p\nu)$ interaction if it is governed by the same constant as the processes of the type $\nu + p \to \tilde{n} + \mu$.

It should be noted that the process $\nu + p \to \nu + p$ could occur in the second order of the weak constant, according to the following diagram

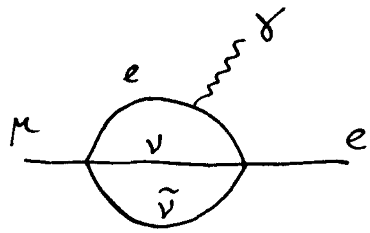


I

This diagram in modern theory leads to divergent expressions, and the estimates of the cross sections are strongly cut-off dependent. It may be recalled that the higher orders of weak interactions were intensively discussed in connection with the so-called "unwanted processes" of the type $\mu \to e + \gamma$, $\mu^- + p \to p + e$ etc., that is the diagrams of the type



II



III

But, in view of discovery of two types of neutrinos, all the processes of types II and III turn out to be strictly forbidden. Indeed, at present one may point to the only processes described by the diagram of type I which is suitable for investigating a possible role of the higher approximations in weak interaction theory as well as the role of strong interactions in suppressing the intermediate states with large momenta.

The role of strong interactions in suppressing large real momenta transferred to the nucleon in the process $\nu + N \to N' + \mu$ presents also a very important task pertaining to an investigation of the energy dependence of the cross sections $\nu + N \to N' + \mu$ in the energy range E = 10 GeV, which will require the construction of accelerators with the proton energies of 300 - - 1000 GeV and with beam intensities of 10^{12} - 10^{13} proton/ sec.

At the initial stages of the search for the $(e\nu)(e\nu)$ interaction it is reasonable to make use of reactors yielding intense fluxes of low energy neutrinos. However, in future the problem of $(e\nu)(e\nu)$ interaction (either as a direct one or as a higher order process) enters into the domain of research at accelerators of high energies and large intensities. The theory leaves room for weak interactions of the type $(pn)(pn)$, which is mixed up with strong interaction.

The existence of such a weak interaction which violates parity would be very essential for the general theory of weak interactions. Here a purely experimental problem arises as to finding weak interactions, however much they violate parity against the background of strong processes.

This extremely difficult experimental problem, nevertheless, deserves attention and calls for persistent search for its possible experimental solutions. It is likely to be an honorable task with which accelerators of moderate energy ($<$ 1 Gev), but of extremely high intensity ($\sim 10^{15}$) are faced.

It should also be of great importance to perform experiments aimed at analyzing the participation of neutral currents both symmetrical $(pp)(pp)$, $(ee)(ee)$ etc. and non-symmetrical $(np)(\Lambda^{0}p)$ involving the violation of strangeness.

Conclusion

The authors are fully aware of the fact that in describing fundamental problems of modern physics a certain subjectivity could not be avoided, though during the preparation of this report, they discussed all these problems with many other theoreticians and experimental workers, to whom they express their deep gratitude.

The authors are also conscious that their forecasts and recommendations are based essentially on modern ideas and recent developments in the theory. However, there is no doubt that further progress in physics will somewhat modify these predictions, the significance of which are at the moment difficult to foresee.

We merely hope that we succeeded to a certain extent in outlining the main trends in the development of elementary particle physics for the years to come. How long these trends will exist depends on the validity of the basic principles underlying modern theory.

The verification of these principles is one of the most fundamental problems the experimental physics of elementary particles is faced with. In particular, the present report described the importance of the verification of

1. Locality, causality and the conservation laws.
2. The existence of an elementary length.
3. CPT - invariance.
4. The problems of the structure of interactions (the relationship between electromagnetic and strong interactions) a study of different types of four-fermion

interactions, the problem of an intermediate boson, different symmetries in strong interactions.

5. Analytical properties of amplitudes (involving Reggistics).

6. Problems concerning elementary particles.

7. Asymptotic behaviour of the cross sections at high energies.

As one can see from this report, in order to reach this goal, it is necessary to construct both accelerators of ultra-high energies and those of modest energies but with intense particle beams which will provide measurements of high accuracy.

L. C. L. Yuan

I wish to make a comment on the very important question of the Regge poles and elementary particle behaviour as mentioned by Professor Blokhintsev. The recent experiments done at Brookhaven and at CERN on the diffraction scattering of proton-proton and pion-proton up to about 20 GeV/c momentum have already demonstrated the invalidity of a single Regge pole picture. More recent results obtained at Brookhaven on the K^+-p, K^--p and antiproton-proton diffraction scattering at high energies also give indications of no shrinkage of the diffrac tion pattern as energy is increased as shown by the pion-proton elastic scattering in contradiction to a shrinkage observed in the proton-proton elastic scattering. Furthermore our results show that there is no indication of the presence of a real component in the forward scattering amplitude of the $\pi^\pm p$ elastic scattering process whereas in the p - p scattering there is perhaps an indication of a real amplitude but certainly not more than 10%.

I would certainly agree with Professor Blokhintsev that not only higher energy but higher intensity accelerators are necessary.

D. I. Blokhintsev

It is now clear that the situation associated with the theory of Regge poles is not as simple and promising as was indicated a year ago. However, it would not be correct to discard this theory. Further theoretical and experimental work is necessary.

It is unfortunate that this disagreement in the experiment on Regge pole theory does not disprove the basic principles of modern theory.

V. P. Dzhelepov

For the consideration of the problem on the experimental investigation of various aspects of high energy physics and the necessity of creating 100-1000 GeV accelerators, it is important to emphasize the fact that many fundamental problems in the physics of elementary particles may be successfully solved by using accelerators of intermediate energies (up to 1 GeV), but with intensities 100-1000 times greater (10^{15}-10^{16} proton/sec) than those which are obtained at the present time with synchrocyclotrons (i.e., 10^{13} proton/sec).

I wish to indicate at this time some of these problems which were discussed in our laboratory. First of all, this complex of problems associated with the verification of the theory of universal weak interaction:

a) The precise investigation of the reaction for the capture of muons by protons in gaseous hydrogen: $\mu^- + p \to n + \nu_\mu$; $\mu^- + p \to n + \nu_\mu + \gamma$, which includes not only the determination of the exact values of the total probabilities but also the measurement of the longitudinal polarization of neutrons in the first of these reactions and the investigation of n-γ correlation in the second.

b) The detailed study of the pion β decay $(\pi^+ \to \pi^0 + e^+ + \nu)$, including determination to within 1% of the total probability, measured at the present time, for 50 cases of the decay of the spectra of e^+ and π^0 mesons and also the determination of the polarization of e^+. This process is in a certain sense, unique, and is not only of interest from the viewpoint of verifying the conservation of the vector current in weak interactions but also in the fact that it will play a fundamental role in every modification in the theory of weak interactions.

c) The determination of the mass of a muon neutrino, for example, as was shown by Goldhaber, according to the radiation decay of a π meson.

d) The effect of the existence of neutral lepton currents which was introduced by B. Pontecorvo -- a problem of fundamental importance in the theory of weak interactions.

e) The single formation of hyperons in nucleon-nucleon collisions due to weak interaction: the cross section of a process of the type $N+N \rightarrow N + \Lambda$ is about 10^{-38} cm^2 as was shown by M. A. Markov and Nguyen Van Hieu at 650 MeV.

An increase in the intensity of pion beams by a factor of 100 or more opens interesting possibilities for determining the form-factors of pions by means of investigating infrequent decay patterns:

$$\pi^0 \begin{array}{l} \nearrow e^+ + e^- \\ \searrow e^+ + e^- + \gamma \end{array} ; \quad \pi^+ \rightarrow e^+ + \nu + \gamma .$$

Experiments carried out at CERN for determining the quantity (g-2) and the scattering of muons by nuclei have evidently shown to a conclusive degree that a valuable contribution may be made toward solving such a fundamental problem in the theory of elementary particles for explaining the limits of applicability of quantum electrodynamics, if muon beams of low energies but very high intensities are used when it is possible to carry out precision measurements.

Finally, there exists a complex of extremely important problems in the region of strong interactions, primarily the study of elastic and inelastic N - N- and π - N-interactions including polarization effects with an accuracy to within 1%.

All this convinces us of the need for seeing to the creation, in the very near future, of accelerators of intermediate energy but with currents of the order of a milliampere, i.e., "meson factory" together with the development of accelerators with very high energies and intensities of about 10^{13} particles/sec.

A. A. Komar

I would like to make some remarks concerning one of the promising directions of experimental physics in the region of high energies, such as the study of processes in colliding electron-positron beams. More specifically, the topic of discussion is the possibility of creating a pair of unstable particles -- resonances -- for these collisions.

Similar processes have been observed recently [Ferbel T. et al., Phys. Rev. Lett., 9, 351 (1962); Baltay C. et al. Ibid., 11, 32 (1963)] for anti-proton-proton collisions, for example,

$$\tilde{p}+p \rightarrow \underset{\searrow p+\pi^+}{N^*_{33}} + \underset{\searrow \tilde{p}+\pi^-}{\tilde{N}^*_{33}}; \quad \tilde{p}+p \rightarrow \underset{\searrow \Lambda+\pi^-}{Y^*_1} + \underset{\searrow \Lambda+\pi^+}{\tilde{Y}^*_1}$$

This positively confirms the favorability of the fact that resonances, in spite of the relatively large widths in isolated cases (N^*_{33}) enter, as a whole, into interactions, i.e., they are known as entities which we have become accustomed to calling particles. This gives us some right to consider electromagnetic interactions of these entities, in particular the creation of pairs of resonances in electron-positron collisions, for example,

$$e^- + e^+ \to \begin{cases} \rho^+ + \rho^- \\ K^* + \bar{K}^* \\ Y_1^* + \bar{Y}_1^* \end{cases}$$

Larger values for the spin of the resonances (1 for ρ and K^*, 3/2 for Y_1^*) than for particles known up to the present (0 and 1/2) lead to the fact that the cross section for the formation of a pair of resonances does not decrease, as is usual, with an increase in energy proportional to E^{-2}. On the other hand, for $E \gg M$ for spins of 1 and 3/2, the cross sections behave as follows:

$$\left(\frac{d\sigma}{d\Omega}\right)_{s=1} \approx \frac{\alpha^2}{16M^2}(1+\cos^2\vartheta),$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{s=\frac{3}{2}} \approx \frac{\alpha^2}{9M^2}\cdot\frac{E^2}{M^2}(1+\cos^2\vartheta),$$

where M is the mass of the created particle (usually, the region of applicability of these formulas is limited by the uniqueness condition). As a result of these processes, the creation of a resonance pair (and, in general, particles with high spins) must predominate in electron-positron collisions at high energies. This fact brings an interesting possibility to light for studying the properties and structure of these unstable formations.